

Simulation of mask “black border” effect in EUV using rigorous models

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Abstract

The opaque mask border blocks the light outside the exposure area and naturally serves as a separation between the neighboring fields. However, in EUV mask the reflectivity of the absorber is no longer negligible. The leakage of light from neighboring exposure fields can induce significant flare at the edge of the field, especially at the corner of the field where three adjacent exposures take place. This is the so-called “black border” (BB) effect in EUV. Experiments have shown that the BB effect can change the CD by 4-9% and 15-20% at the edge and corner of the field, respectively. The BB effect can be modeled by combining the flare map of a mask and the additional flare due to the BB. In this paper we study the BB effect in EUV with a rigorous lithographic model. We have evaluated the CD uniformity impact for the variables of the BB region such as the size and the reflectivity. The study demonstrates that modeling and then performing optical proximity correction (OPC) is a promising method to compensate for the BB effect.

Keywords: EUV simulation, black border, flare, OPC

Introduction

What are black border effects and the compensation approaches?

- **Image border on mask** → defines exposure field
 - Optical: “Black border (BB)” = Cr. with transmission of <0.1%
 - EUV: “Black border (BB)” = absorber, with residual EUV reflectivity of 1 – 3%
- **Wafer exposure:** light reflected from the image border impacts CD behavior in neighboring fields
 - Field edges: CD changes: 4 – 9%
 - Field corners: CD changes: 15 – 20%
- **BB light shield approaches by mask treatments** [1-5] :
 - Multilayer (ML) etched type: residual reflectivity=0, but cost, defects, displacement,...
 - Thicker absorber type: residual reflectivity>0, cost, ...
- **Modeling approach**
 - Apply PSF and mask pattern density map to generate the mask flare map.
 - Construct the additional light contribution due to the exposures of neighboring fields into a local “BB flare map” and add on top of the mask flare map.
 - Apply rigorous mask and resist models
- **Compensation approach**
 - Apply optical proximity correction (OPC)

Black Border effect by a local flare model

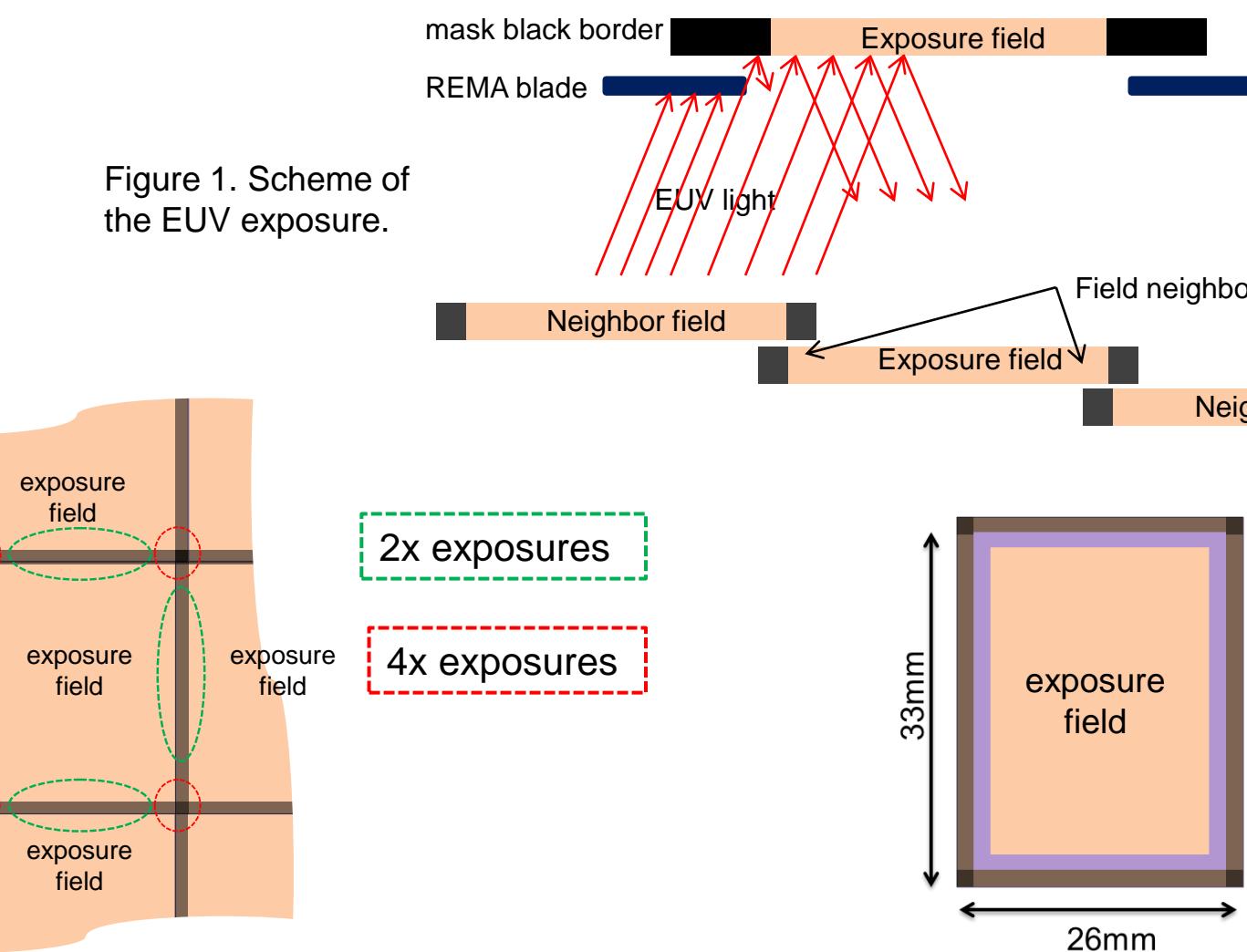


Figure 1. Scheme of the EUV exposure.

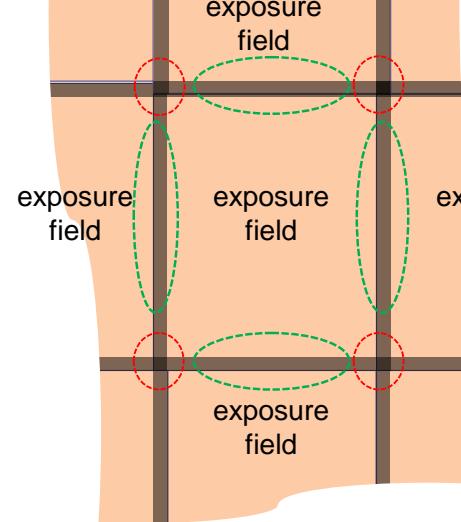


Figure 2. Top-down view of the exposure fields.

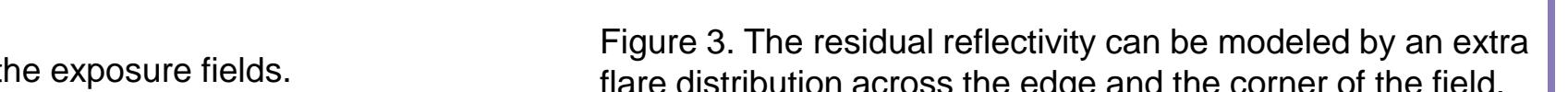


Figure 3. The residual reflectivity can be modeled by an extra flare distribution across the edge and the corner of the field.

The BB model in a lithography simulation tool

- A sigmoid function is designed to model the transition of the residual reflectivity from the border to the inner field.
- b : the border width (typically 0-200 um) with a reflectivity of R (typically ~1-3%).
- a : the transition width (typically 100-200um) representing the half-shadow (penumbra) of the REMA blades.
- The total flare consists of **Short Range Flare + Long Range Flare + BB Flare**.

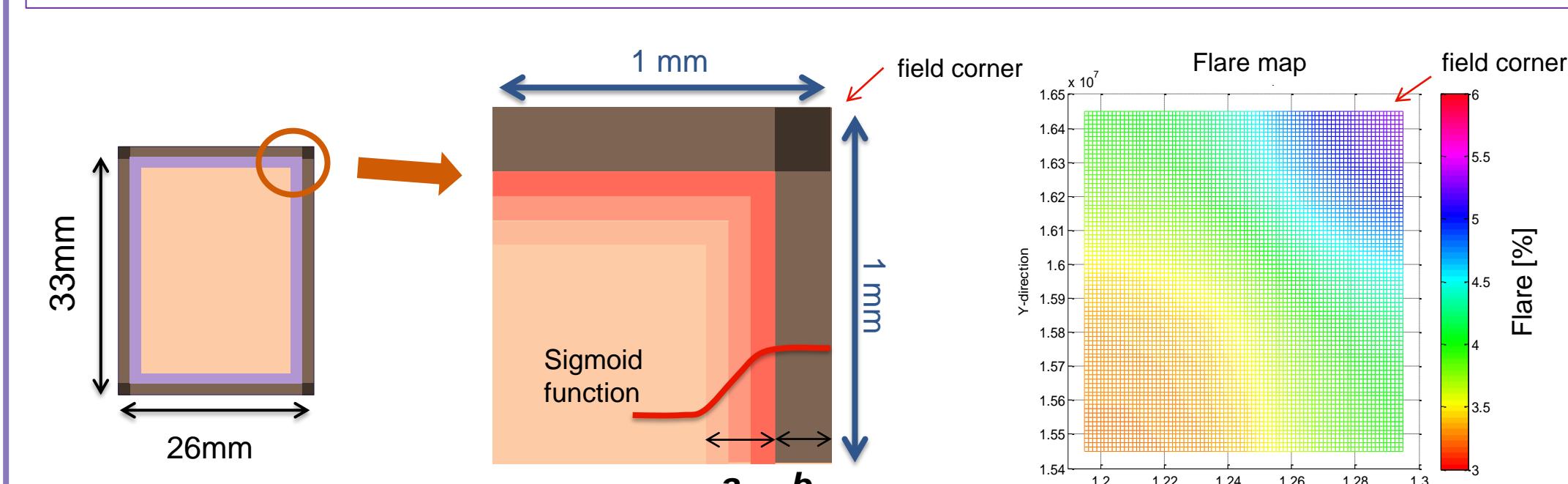


Figure 4. Left: The exposure fields layout. Middle: A zoom-in view of the mask corner. Right: The simulated flare map with the BB model at the following conditions: $a = 200\text{um}$. $b = 200\text{um}$. $R = 1.26\%$. A homogeneous flare map of 3% across the whole mask is pre-assumed.

Simulations of CHs and L/S using rigorous models

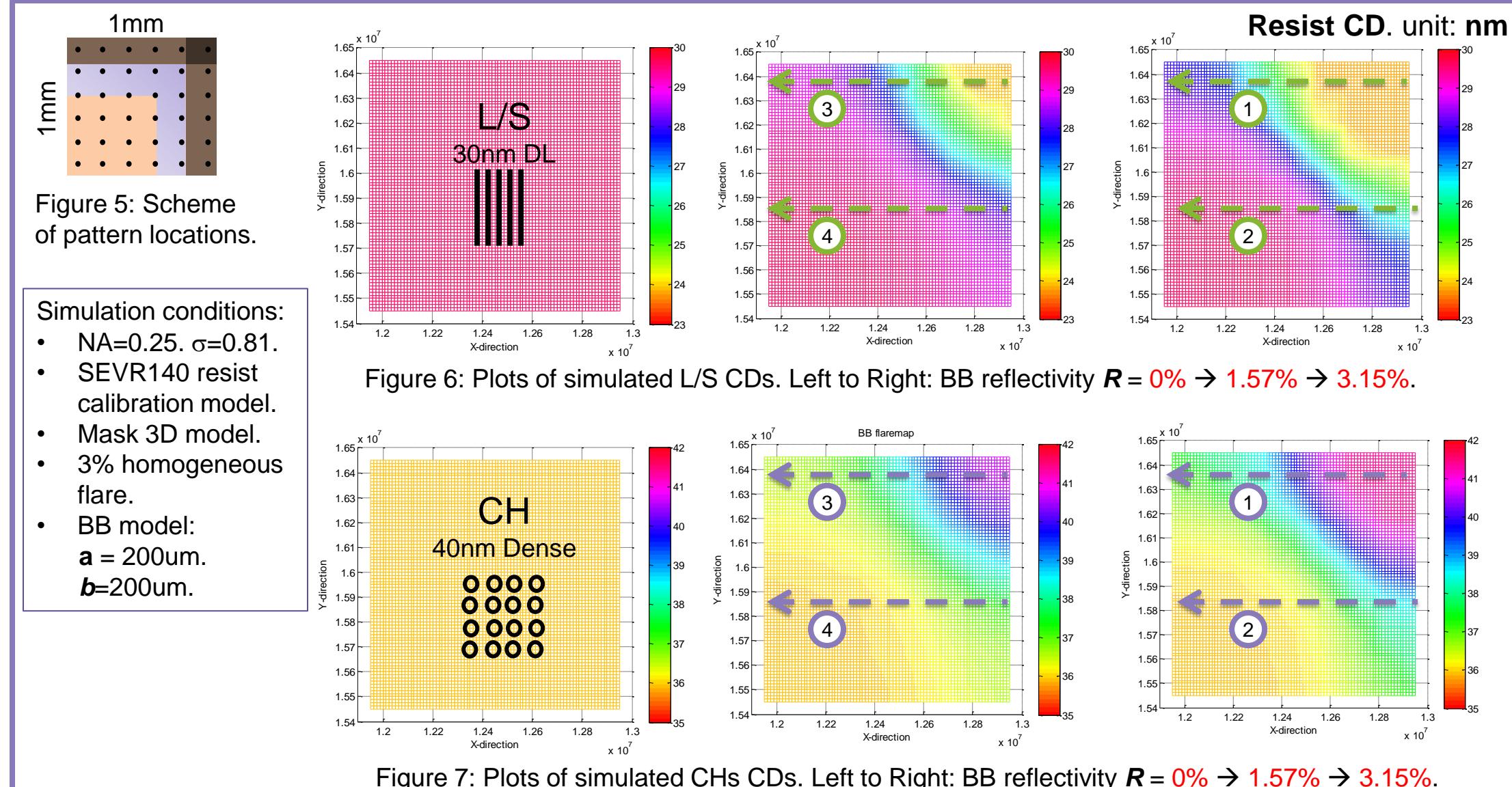


Figure 5: Scheme of pattern locations.
 Figure 6: Plots of simulated L/S CDs. Left to Right: BB reflectivity $R = 0\% \rightarrow 1.57\% \rightarrow 3.15\%$.
 Figure 7: Plots of simulated CHs CDs. Left to Right: BB reflectivity $R = 0\% \rightarrow 1.57\% \rightarrow 3.15\%$.

Simulations and Wafer Results

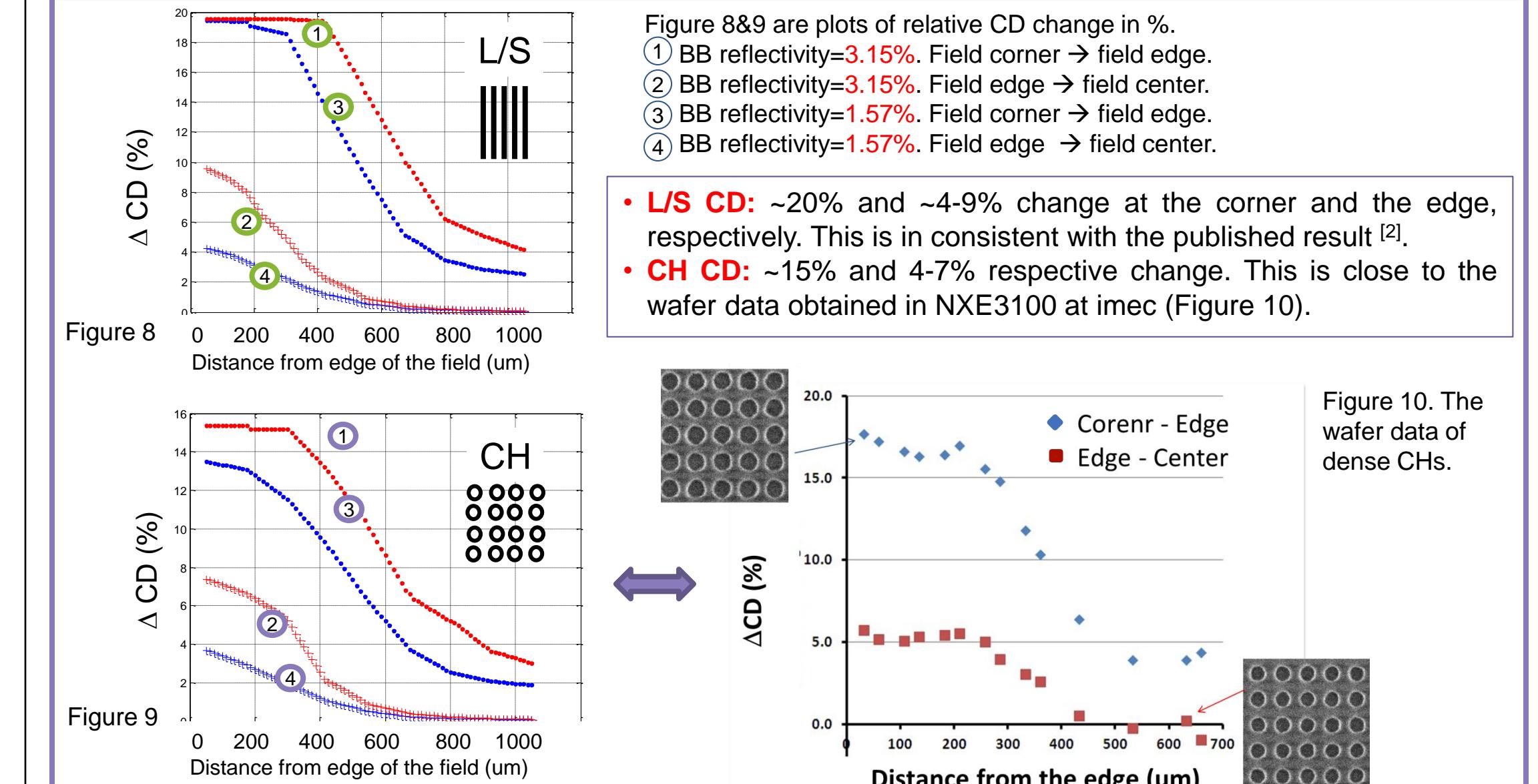


Figure 8&9 are plots of relative CD change in %.
 ① BB reflectivity=3.15%. Field corner → field edge.
 ② BB reflectivity=3.15%. Field edge → field center.
 ③ BB reflectivity=1.57%. Field corner → field edge.
 ④ BB reflectivity=1.57%. Field edge → field center.
 • **L/S CD:** ~20% and ~4-9% change at the corner and the edge, respectively. This is in consistent with the published result [2].
 • **CH CD:** ~15% and 4-7% respective change. This is close to the wafer data obtained in NXE3100 at imec (Figure 10).
 Figure 10. The wafer data of dense CHs.

CDU Impact of BB Width

CHs NA=0.25, $\sigma=0.81$. 40nm dense CHs, SEVR140 resist calibration model. Mask 3D model. A 3% homogenous flare. BB model: $a = 200\text{um}$. $R = 1.26\%$.

The increase of BB width by 100 um brings CDU (3σ) rising by ~0.9nm.

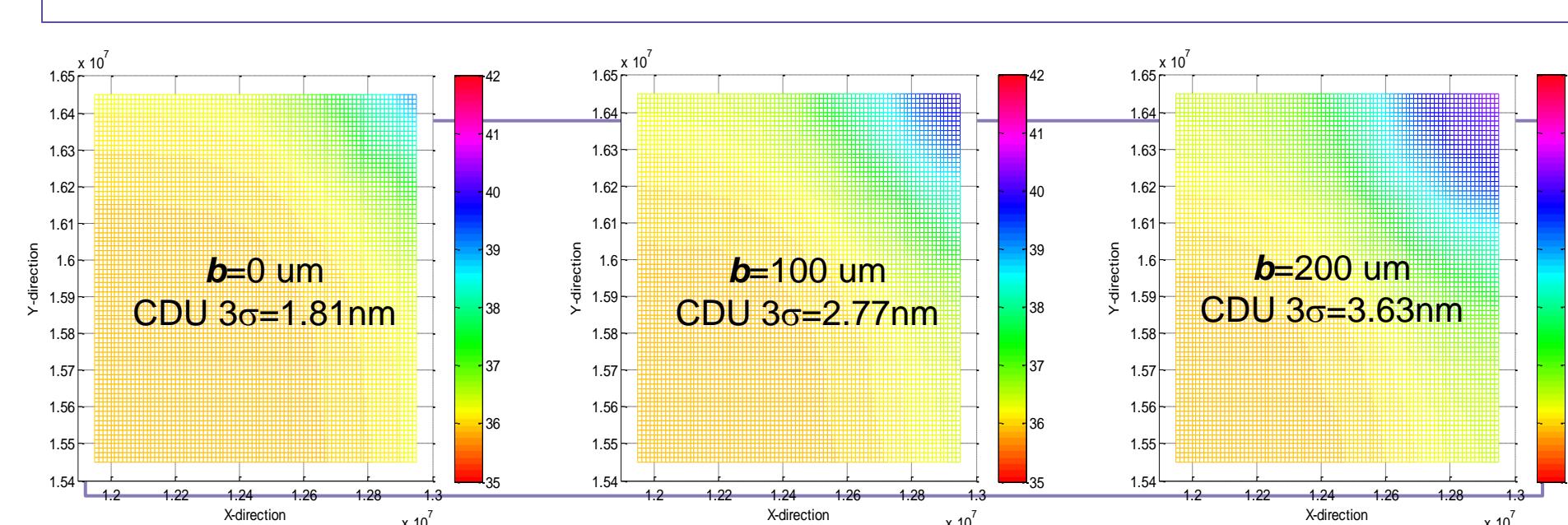


Figure 11. The CD changes at different BB width: 0um → 100um → 200um. A 100um BB width.

Discussions and Summary

- The BB effect can be modeled by adding a local intensity distribution on top of the flaremap of the mask.
- A Sigmoid function is designed to model the local effects and simulate the gradual reduction of the “total flare” from the field corner to the inner field. This model is available in Sentaurus Lithography.
- Rigorous simulations are based on a calibrated resist model, the Mask 3D model and the fitted PSF of the EUV tool. Results were compared to the wafer data obtained on the NXE3100 EUV tool at imec.
- Simulations clearly show the highest CD change occurs at the field corner by ~15-20% for 30nm dense L/S and 40nm dense CH at the assumed conditions. Simulation results are consistent with the experiments.
- Simulations also show that the BB width has a direct impact on the CDU: A BB region with 100um wider consumes ~0.9nm CDU (3σ) budget. This result indicates that an accurate control of REMA is required.
- The presented model predicts well the CD changes due to BB effects. Thus, OPC can be applied as a compensation technique, avoiding the costly light shielding mask treatments.

References and Acknowledgments

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